COMPONENT PART NOTICE

THIS PAPER IS A COMPONENT PART OF THE FOLLOWING COMPILATION REPORT:

TITLE: Minutes of the Explosives Safety Seminar (22nd) Held in Anaheim, California on 26-28 August 1986. Volume 1.

TO ORDER THE COMPLETE COMPILATION REPORT, USE AD-A181 274.

THE COMPONENT PART IS PROVIDED HERE TO ALLOW USERS ACCESS TO INDIVIDUALLY AUTHORED SECTIONS OF PROCEEDING, ANNALS, SYMPOSIA, ETC. HOWEVER, THE COMPONENT SHOULD BE CONSIDERED WITHIN THE CONTEXT OF THE OVERALL COMPILATION REPORT AND NOT AS A STAND-ALONE TECHNICAL REPORT.

THE FOLLOWING COMPONENT PART NUMBERS COMPRISE THE COMPILATION REPORT:

AD#: P005 302 thru P005 349 AD#:

AD#: AD#:

AD#: AD#:

| Accession For | |
|---|---|
| NTIS GRA&I | X |
| DTIC TAB | ☐ |
| Unannounced | ☐ |
| Justification | |
| By | |
| Distribution/ | |
| Availability Codes | |
| Dist | Avail and/or Special |
| A-1 | |



DTIC FORM 463 MAR 85

OPI: DTIC-TID

# BLAST LOADS BEHIND VERTICAL WALLS

Prepared for the

Twenty-Second DoD Explosives Safety Seminar

Anaheim, California

26-28 August 1986

by

Mary E. Beyer

Naval Civil Engineering Laboratory

Port Hueneme, California 93043

# BLAST LOADS BEHIND VERTICAL WALLS

by Mary E. Beyer

Naval Civil Engineering Laboratory

Port Hueneme, California 93043

## 1.0 PURPOSE

This paper presents preliminary design criteria for vertical cantilever blast deflector walls intended to reduce the blast environment from explosions detonated immediately behind the walls. The design criteria relates the peak blast overpressure, total blast impulse, and effective duration of the overpressure in a format that facilitates the design of blast deflector walls and the prediction of the blast environment behind the walls. The preliminary criteria presented in this paper were derived from high explosive tests completed in 1985 (Reference 1 and 2). Additional tests are scheduled for September 1986 (Reference 3), and final design criteria will then be developed.

## 2.0 PROBLEM

Vehicle bombs are a major terrorist threat to the security and safety of inhabited facilities. One possible plan to reduce the danger of the vehicle bombs is to construct a vertical cantilever wall at a safe distance from the nearest people and property. The wall is designed to stop the vehicle and to prevent breaching of the wall from detonation of the bomb. The wall serves to detonate the vehicle bomb a safe distance away from the inhabited facilities.

The procedure for designing the wall to survive the vehicle impact and bomb explosion is undefined. Some criteria exist, but the reliability of the design process decreases with increasing vehicle strike velocity and bomb size, and decreasing distance between the wall and point of detonation. The barrier could be a solid reinforced concrete wall, a composite wall of sand between two reinforced concrete walls connected by shear diaphragms, or a solid reinforced concrete wall backed by a massive earth berm (retaining wall).

One problem in the design of a vehicle bomb barrier is determining where to site the wall relative to the buildings to be protected. Criteria exist for predicting the damage to buildings, given the blast environment at the building. However, no criteria exist for predicting the blast environment behind a vertical wall. Based on the present technology, the

site location must neglect any benefits from the wall on reducing the blast environment. Theoretically, the wall serves as a blast deflector shield which reduces the blast environment behind the wall. The effectiveness of the wall in suppressing the blast environment depends on the wall height, and the explosive size and location as illustrated in Figure 1.

The blast environment behind the wall may be further suppressed by locating a canopy near the top of the wall on the loaded side of the wall, as shown in Figure 2. This concept assumes that the canopy would focus shock waves in a safe direction. The canopy could shatter, and be blown away by the force of the explosion, but it would probably remain in place long enough to mitigate the shock waves spilling over the wall. The effectiveness of the canopy depends on its mass, surface area, and location.

Blast pressures measured in high-explosive tests of cubicles by NCEL (Reference 4) demonstrate that reductions in the blast environment behind walls do occur. However, these tests did not simulate the condition of a bomb located adjacent to a long vertical wall designed to prevent shock waves from clearing around the ends of the wall.

Design criteria for the blast environment (including peak blast overpressure, total blast impulse, and effective duration of the overpressure), behind a wall would allow site planners to account for any benefit from the wall on the safe distance required from a vehicle bomb barrier to an inhabited building. The design blast loads must be related to the critical parameters associated with the characteristics of the wall, bomb, and the point of interest behind the wall, as illustrated by the curves in Figures 1 and 2.

## 3.0 TESTS

### 3.1 Objective

The objective of this test program was to obtain blast overpressure data from high-explosive tests, using a small scale wall, to empirically derive criteria for the design blast loading at any point behind a vertical blast deflector wall. The criteria will express the peak blast overpressure, B (psi), blast impulse, I (psi-msec), and effective load duration, T (msec), as functions of the net explosive weight, W (lb TNT equivalent), wall height, H (feet), wall length, L (feet), distance to point of interest behind wall, R (feet), elevation of point of interest behind wall, h (feet), charge-to-wall distance, r (feet), elevation of charge above ground, z (feet), canopy width, L' (feet), canopy elevation above ground H' (feet), and canopy mass, w ($lb/ft^2$).

The measured blast environment behind the wall will be compared with existing relationships for a surface burst without a wall. The benefits of a vertical wall and a vertical wall plus canopy in reducing the blast environment will be assessed.

## 3.2 Test Setup

The wall tests were performed at the Terminal Effects Research and Analysis Group (TERA) of the New Mexico Institute of Mining and Technology in Socorro, New Mexico. The test schedule is shown in Table 1.

The test structure was a vertical cantilever wall, 2.25 feet high and 28.67 feet long. The wall was constructed of steel armor plate as shown in Figure 3. This test structure is a one-sixth geometric scale model of a 13.5-foot-high by 172-foot-long cantilever wall.

The canopies used for tests 2, 3, 5, 6, and 7 were six-guage or twelve-guage steel sheet metal. Three canopy designs were used in the testing (width = 1.0 feet and density = 4.38 psf; width = 1.0 feet and density = 8.13 psf; and width = 1.5 feet and density = 8.13 psf). The length of each canopy was ten feet. The canopy mass was chosen to represent the equivalent of a 4-inch-thick reinforced concrete slab. The canopies were attached to the wall by a series of tack welds. The tack welding provided the support for the canopy to keep it perpendicular to the wall, but did not prevent the canopy from being blown off the wall when the explosive charge was detonated. For tests 9 and 10, the canopies were supported by several rebar tack welded perpendicular to the wall; the canopies used in tests 9 and 10 were not attached to the wall by any welds.

The test program involved three charge weights ($W_{C4}$ = 1.0, 8.0, and 15.0 pounds C4 explosive). The explosives used in the tests were spherical composition C4 charges. Each explosive charge was placed in a lightweight cheesecloth pouch and suspended by string from a rebar welded perpendicular to the wall. The distance from the center of the charge to the wall and to the ground was one foot. Conversion of charge weight from composition C4 to TNT was made using an equivalency value of 1.129 (1.129 pounds of TNT is equal to 1.0 pounds of C4, Reference 5). According to modeling laws, detonating a 1.0-pound test charge adjacent to the scale model wall is equivalent to detonating a 244-pound charge adjacent to the prototype wall, and detonating a 15.0-pound test charge (maximum test charge) adjacent to the scale model wall is equivalent to detonating a 3,660-pound bomb adjacent to the prototype wall.

## 3.3 Testing Procedure

Pressure transducers were located along two horizontal gage lines emanating from the charge as shown in Figure 4. One gage line was set up normal to the wall, and the other was 45 degrees to the wall. Each gage line had transducers located at both the ground surface (h = 0), and at the elevation of the wall (h = H = 2.25 feet). The elevated gages farthest from the wall were 4.5 feet above the ground surface. The transducers normal to the wall were located at R = 2.25, 4.5, 6.75, 9.0, 13.5, and 18.0 feet from the wall. This corresponds to 1H, 2H, 3H, 4H, 6H, and 8H, with the distance from the transducers to the wall given in multiples of the wall height. The gages at 45 degrees to the wall were located at R = 4.5, 9.0, and 18.0 feet from the wall. This corresponds to 2H, 4H, and 8H, with the distance from the transducers to the wall given in multiples of the wall height. This arrangement required eighteen transducers in each test. Based on the one-sixth scale model, the measurement points correspond to full-scale $13.5 \leq R \leq 108$ feet and $0 \leq h \leq 13.5$ feet (h = 27 feet for the two elevated gages farthest from the wall).

Gage mounts for the elevated gages were stainless steel disk baffles supported by steel gage stands oriented in the direction of the charge. The surface gages were installed flush with the ground.

Analog pressure data was electronically recorded on magnetic tape using two tape recorders.

## 3.4 Test Results

The analog data obtained from each test was digitized, and computer plots of the pressure-time history at each pressure transducer were prepared. The plots showed the peak blast overpressure and the total impulse measured at each gage. The peak pressure, total impulse, and gage locations for each test are summarized in Tables 2 through 11.

In order to compare the test results with the blast environment produced from an explosion without a wall, values for the peak pressure and total impulse were required for the detonation of 1.0, 8.0, and 15.0 pound charges with no blast deflector wall. These values were obtained using the hemispherical surface burst graphs in the revised NAVFAC P-397 Volume II (Reference 6). The calculated values of the peak pressure and total impulse resulting from the detonation of a charge without a wall are given in Table 12.

The barricade was not damaged in any of the ten tests. The canopies were all completely blown away from the wall.

Peak pressure and scaled impulse were plotted against scaled ground distance for each charge weight, showing results for each test with and without canopies, and the calculated values for surface pressure with no wall. These plots are given in Figures 5 through 10. Separate plots were made for the results from the elevated gages and the surface gages, and for the 45 degree gage line and the 90 degree gage line.

In general, there was a reduction in peak pressure and impulse behind the wall when the test results are compared to the calculated values for the blast environment produced from an explosion without a wall.

### 3.5 Additional Testing

From the results of the tests in October 1985, it was determined that additional testing would be required before blast load criteria could be developed. Values for the peak pressure and total impulse resulting from the detonation of a charge without a wall were calculated using the hemispherical surface burst graphs in the revised NAVFAC P-397. Additional tests are planned to provide data to compare with these values from P-397. Also, blast overpressure data from tests using the small-scale wall are planned for validation of previous results. The test schedule for these tests is given in Table 13.

## 4.0 PRELIMINARY DESIGN CRITERIA

Presented in Figures 11 through 15 are preliminary design criteria for the blast environment behind vehicle bomb barriers. The criteria are considered to be preliminary and will require further test validation.

Use of the criteria requires interpolation between values corresponding to the curves in Figures 11 through 15. Linear interpolation on a log-log scale is recommended for obtaining an intermediate value of any parameter, using either mathematical relationships or log-log graph paper.

In Figure 11, the blast overpressure, B, and scaled impulse, $I/W^{1/3}$ are plotted as a function of the scaled distance, $R/W^{1/3}$, for several values of the scaled wall height, $H/W^{1/3}$. Each curve is for the results from the surface gages, for tests with no canopy.

In Figure 12, the blast overpressure, B, and scaled impulse, $I/W^{1/3}$ are plotted as a function of the scaled distance, $R/W^{1/3}$, for several values of the scaled canopy mass, $w/W^{1/3}$. Each curve is for the results from the surface gages,

for tests with the scaled wall height, $H/W^{1/3}$, equal to 0.88 $ft/lb^{1/3}$.

In Figure 13, the blast overpressure, B, and scaled impulse, $I/W^{1/3}$ are plotted as a function of the scaled distance, $R/W^{1/3}$, for several values of the scaled canopy mass, $w/W^{1/3}$. Each curve is for the results from the surface gages, for tests with the scaled wall height, $H/W^{1/3}$, equal to 1.08 $ft/lb^{1/3}$.

In Figure 14, the blast overpressure, B, and scaled impulse, $I/W^{1/3}$ are plotted as a function of the scaled distance, $R/W^{1/3}$, for several values of the scaled canopy mass, $w/W^{1/3}$. Each curve is for the results from the surface gages, for tests with the scaled wall height, $H/W^{1/3}$, equal to 2.16 $ft/lb^{1/3}$.

In Figure 15, the blast overpressure, B, and scaled impulse, $I/W^{1/3}$ are plotted as a function of the scaled distance, $R/W^{1/3}$, for several values of the scaled wall height, $H/W^{1/3}$. Each curve is for the results from the elevated gages, for tests with no canopy.

## 5.0 FUTURE WORK

Additional explosive tests are planned for September 1986. These tests are considered important to validate the results of the previous test series, and to provide data for blast overpressure with no blast deflector wall. The test results will be combined with previous results to empirically derive design criteria for the blast environment behind a vehicle bomb barrier.

## 6.0 REFERENCES

1. Naval Civil Engineering Laboratory. Technical Memorandum TM 51-85-14: Test plan for development of criteria for design blast loads behind a blast deflector wall, by M. Beyer and W. Keenan. Port Hueneme, Calif., Oct 1985.

2. Naval Civil Engineering Laboratory. Technical Memorandum TM 51-86-08: Test Data Report: Development of criteria for design blast loads behind a blast deflector wall, by M. Beyer, Port Hueneme, Calif., Jan 1986.

3. Naval Civil Engineering Laboratory. Technical Memorandum TM 51-86-11: Test plan for additional testing for development of criteria for design blast loads behind a blast deflector wall, by M. Beyer, Port Hueneme, Calif., Jun 1986.

4. Civil Engineering Laboratory. Technical Report R-828: Blast environment from fully and partially vented explosions in cubicles, by W. A. Keenan and J. E. Tancreto. Port Hueneme, Calif., Nov 1975.

5. US Department of Energy. DOE/TIC-11268: A manual for the prediction of blast and fragment loadings on structures, by W. Baker, J. Kulesz, P. Westine, P. Cox, and J. Wilbeck. Nov 1980, Appendix A, Table 6.

6. Naval Facilities Engineering Command. NAVFAC P-397, Army TM 5-1300 and Air Force AFM 88-22, Special Publication ARLCD-SP-84001: Structures to resist the effects of accidental explosions. Washington, D. C., Jun 1969, Volume 2.

## 7.0 LIST OF SYMBOLS

B = Peak Blast Overpressure, (psi)

I = Blast Impulse, (psi-msec)

T = Effective Load Duration, (msec)

W = Net Explosive Weight, (lbs TNT equivalent)

$W_{C4}$ = Net Explosive Weight, (lbs Composition C4 explosive)

H = Wall Height, (feet)

L = Wall Length, (feet)

R = Distance to Point of Interest Behind Wall, (feet)

h = Elevation of Point of Interest Behind Wall, (feet)

r = Charge-to-wall Distance, (feet)

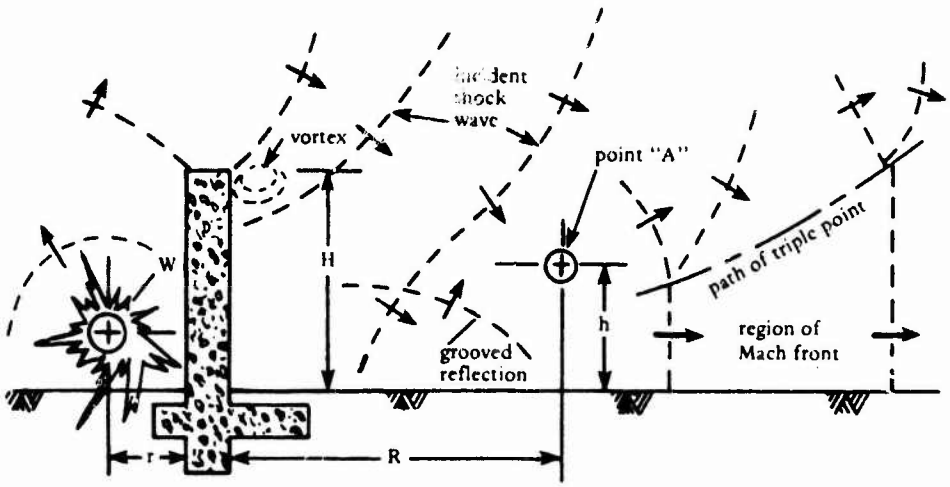
z = Elevation of Charge Above Ground, (feet)

L' = Canopy Width, (feet)

H' = Canopy Elevation Above Ground, (feet)

w = Canopy Mass, ($lb/ft^2$)

Z = Scaled Distance to Point of Interest Behind Wall, $R/W^{1/3}$, ($feet/lb^{1/3}$)



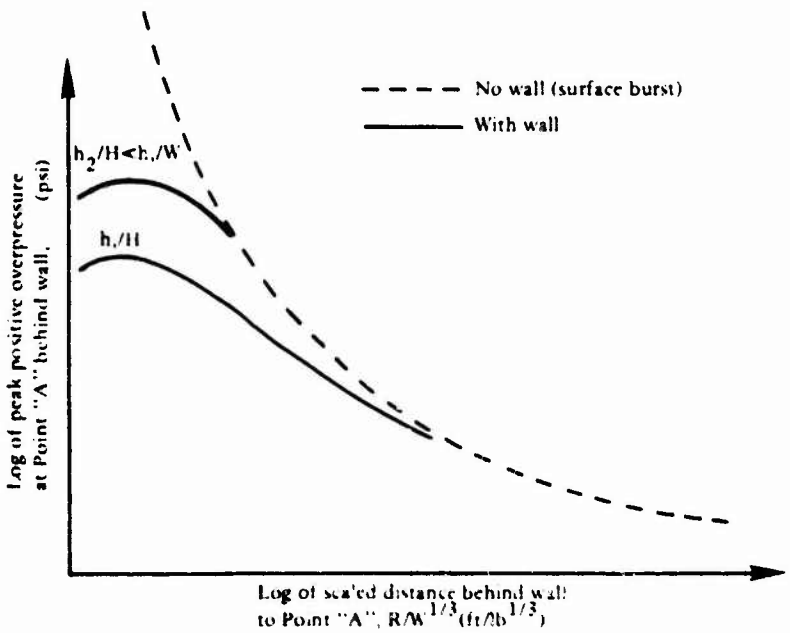
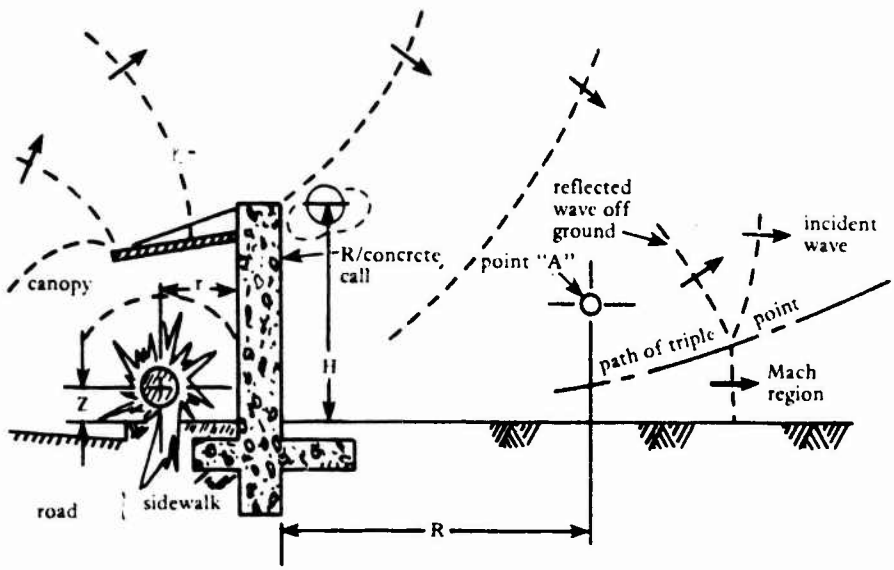




Figure 1. Blast deflector wall and blast environment behind wall.



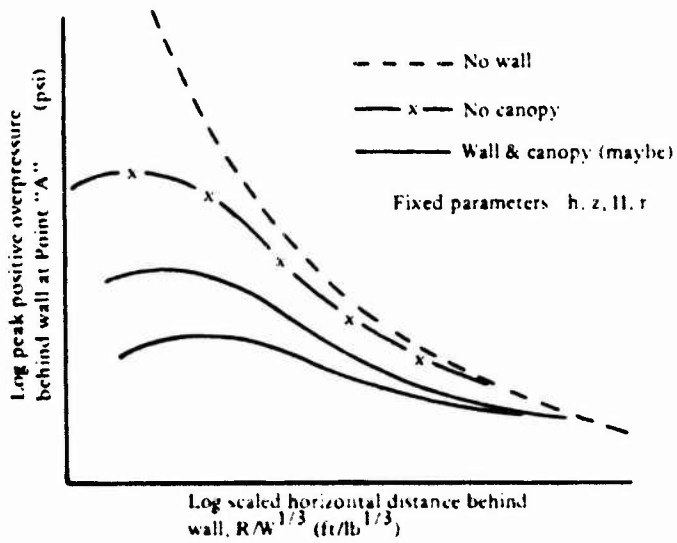
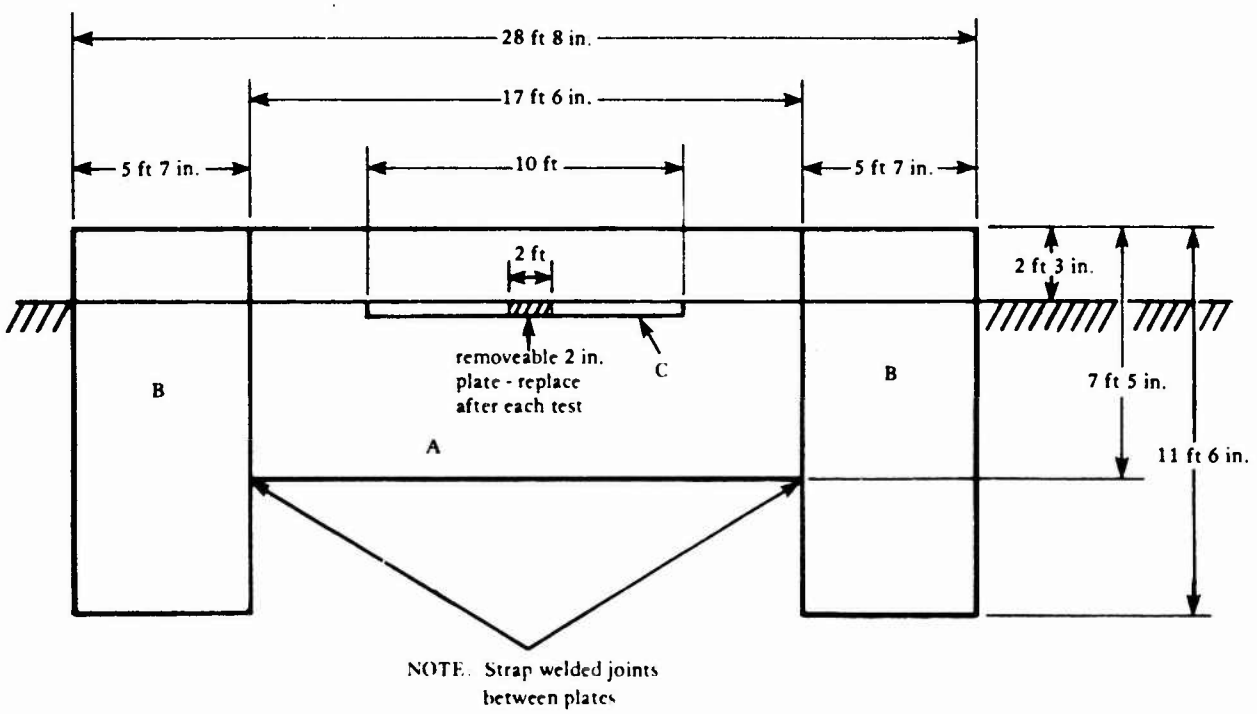




Figure 2. Canopy wall and blast environment behind wall.

TABLE 1. TEST SCHEDULE (Completed in 1985)

| TEST NO. | $W_{C4}$ (lbs) | $H/W^{1/3}$ | w (psf) | $w/W^{1/3}$ | L' (ft) | r (ft) | z (ft) |
|---|---|---|---|---|---|---|---|
| 1 | 1.0 | 2.16 | 0 | - | 1.0 | 1.0 | 1.0 |
| 2 | 1.0 | 2.16 | 4.38 | 4.21 | 1.0 | 1.0 | 1.0 |
| 3 | 1.0 | 2.16 | 8.13 | 7.81 | 1.0 | 1.0 | 1.0 |
| 4 | 8.0 | 1.08 | 0 | - | 1.0 | 1.0 | 1.0 |
| 5 | 8.0 | 1.08 | 4.38 | 2.10 | 1.0 | 1.0 | 1.0 |
| 6 | 8.0 | 1.08 | 8.13 | 3.90 | 1.0 | 1.0 | 1.0 |
| 7 | 8.0 | 1.08 | 8.13 | 3.90 | 1.5 | 1.0 | 1.0 |
| 8 | 15.0 | 0.88 | 0 | - | 1.0 | 1.0 | 1.0 |
| 9 | 15.0 | 0.88 | 4.38 | 1.71 | 1.0 | 1.0 | 1.0 |
| 10 | 15.0 | 0.88 | 8.13 | 3.17 | 1.0 | 1.0 | 1.0 |



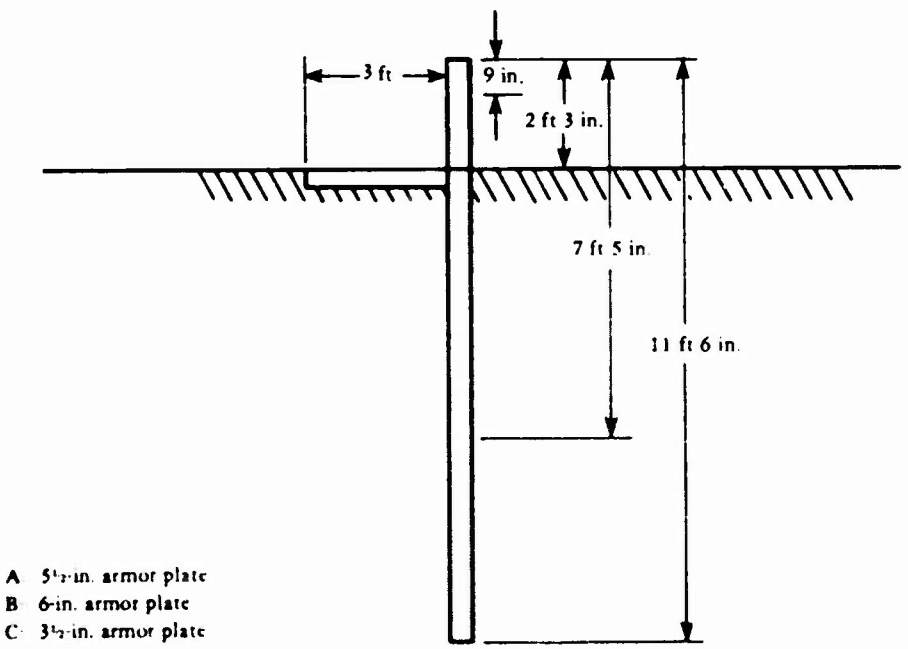




Figure 3. Test wall.

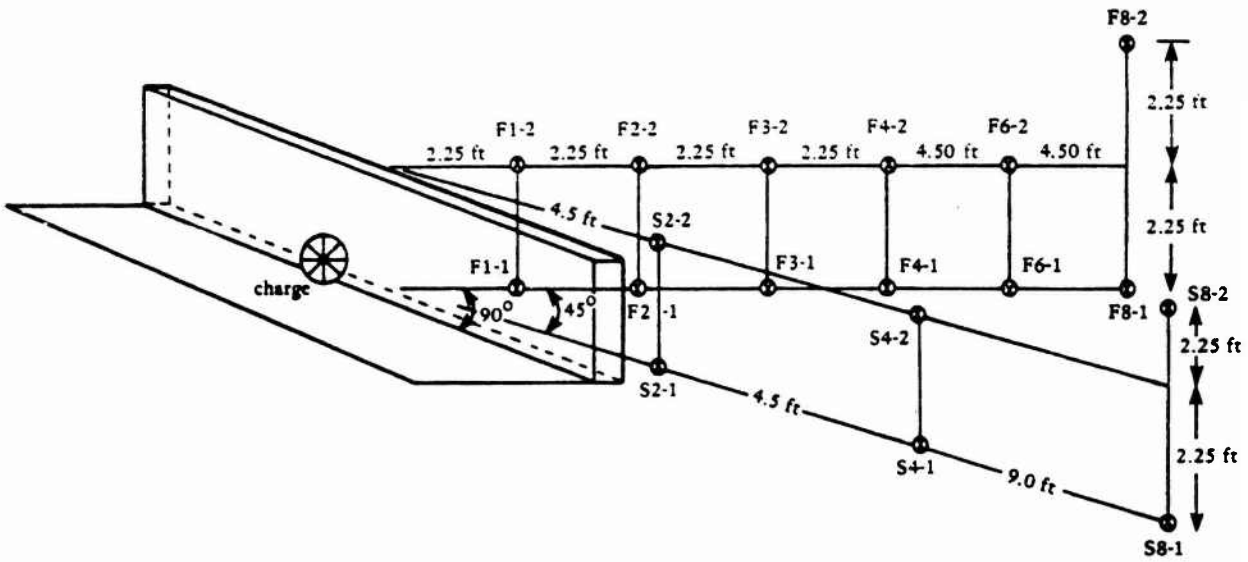



Figure 4. Location of gage lines and pressure transducers.

TABLE 2. TEST 1 RESULTS
Charge Weight = 1.02 lbs
No Canopy

| Gage No. | Range R (ft) | Elevation h (ft) | Peak Side-on Overpressure (psi) | Total Impulse (psi-msec) |
|---|---|---|---|---|
| F1-1 | 2.25 | 0 | 15.72 | 13.0 |
| F1-2 | 2.25 | 2.25 | 15.08 | 9.0 |
| F2-1 | 4.50 | 0 | 8.32 | 9.0 |
| F2-2 | 4.50 | 2.25 | 6.28 | 8.0 |
| F3-1 | 6.75 | 0 | 7.08 | 8.0 |
| F3-2 | 6.75 | 2.25 | 3.23 | 6.0 |
| F4-1 | 9.00 | 0 | 6.42 | 6.0 |
| F4-2 | 9.00 | 2.25 | 3.80 | 6.0 |
| F6-1 | 13.50 | 0 | 3.52 | 6.0 |
| F6-2 | 13.50 | 2.25 | 1.87 | 5.0 |
| F8-1 | 18.00 | 0 | 3.60 | 5.0 |
| F8-2 | 18.00 | 4.50 | 2.31 | 4.0 |
| S2-1 | 4.50 | 0 | 13.29 | 9.0 |
| S2-2 | 4.50 | 2.25 | 9.46 | 7.0 |
| S4-1 | 9.00 | 0 | 7.63 | 6.0 |
| S4-2 | 9.00 | 2.25 | 3.06 | 5.0 |
| S8-1 | 18.00 | 0 | 2.87 | 4.0 |
| S8-2 | 18.00 | 2.25 | 1.53 | 4.0 |

TABLE 3. TEST 2 RESULTS
Charge Weight = 1.02 lbs Canopy Weight = 45.5 lbs
Canopy Size = 12 1/8" x 10' 3/4" x 0.108"

| Gage No. | Range R (ft) | Elevation h (ft) | Peak Side-on Overpressure (psi) | Total Impulse (psi-msec) |
|---|---|---|---|---|
| F1-1 | 2.25 | 0 | 6.44 | 10.0 |
| F1-2 | 2.25 | 2.25 | 6.77 | 7.0 |
| F2-1 | 4.50 | 0 | 3.89 | 7.0 |
| F2-2 | 4.50 | 2.25 | 2.87 | 5.0 |
| F3-1 | 6.75 | 0 | 3.66 | 6.0 |
| F3-2 | 6.75 | 2.25 | 2.55 | 5.0 |
| F4-1 | 9.00 | 0 | 3.66 | 5.0 |
| F4-2 | 9.00 | 2.25 | 2.49 | 5.0 |
| F6-1 | 13.50 | 0 | 2.56 | 5.0 |
| F6-2 | 13.50 | 2.25 | 1.72 | 5.0 |
| F8-1 | 18.00 | 0 | 2.52 | 4.0 |
| F8-2 | 18.00 | 4.50 | 2.39 | 4.0 |
| S2-1 | 4.50 | 0 | 4.95 | 7.0 |
| S2-2 | 4.50 | 2.25 | 4.28 | 6.0 |
| S4-1 | 9.00 | 0 | 5.68 | 6.0 |
| S4-2 | 9.00 | 2.25 | 2.51 | 5.0 |
| S8-1 | 18.00 | 0 | 2.96 | 4.0 |
| S8-2 | 18.00 | 2.25 | 1.34 | 3.0 |

TABLE 4. TEST 3 RESULTS

Charge Weight = 1.02 lbs  Canopy Weight = 78.5 lbs

Canopy Size = 11 7/8" x 10' 3/4" x 0.196"

| Gage No. | Range R (ft) | Elevation h (ft) | Peak Side-on Overpressure (psi) | Total Impulse (psi-msec) |
|---|---|---|---|---|
| F1-1 | 2.25 | 0 | 8.40 | 11.0 |
| F1-2 | 2.25 | 2.25 | 5.28 | 9.0 |
| F2-1 | 4.50 | 0 | 3.84 | 7.0 |
| F2-2 | 4.50 | 2.25 | 3.20 | 6.0 |
| F3-1 | 6.75 | 0 | 3.35 | 7.0 |
| F3-2 | 6.75 | 2.25 | 2.81 | 6.0 |
| F4-1 | 9.00 | 0 | 3.40 | 6.0 |
| F4-2 | 9.00 | 2.25 | 2.73 | 5.0 |
| F6-1 | 13.50 | 0 | 3.05 | 5.0 |
| F6-2 | 13.50 | 2.25 | 1.34 | 5.0 |
| F8-1 | 18.00 | 0 | 1.66 | 4.0 |
| F8-2 | 18.00 | 4.50 | 1.42 | 4.0 |
| S2-1 | 4.50 | 0 | 4.91 | 7.0 |
| S2-2 | 4.50 | 2.25 | 4.67 | 7.0 |
| S4-1 | 9.00 | 0 | 5.57 | 6.0 |
| S4-2 | 9.00 | 2.25 | 2.21 | 4.0 |
| S8-1 | 18.00 | 0 | 2.96 | 4.0 |
| S8-2 | 18.00 | 2.25 | 1.26 | 4.0 |

TABLE 5. TEST 4 RESULTS

Charge Weight = 8.0 lbs

No Canopy

| Gage No. | Range R (ft) | Elevation h (ft) | Peak Side-on Overpressure (psi) | Total Impulse (psi-msec) |
|---|---|---|---|---|
| F1-1 | 2.25 | 0 | 29.84 | 36.0 |
| F1-2 | 2.25 | 2.25 | 29.57 | 22.0 |
| F2-1 | 4.50 | 0 | 36.00 | 29.0 |
| F2-2 | 4.50 | 2.25 | 21.83 | 23.0 |
| F3-1 | 6.75 | 0 | 26.85 | 32.0 |
| F3-2 | 6.75 | 2.25 | 13.98 | 28.0 |
| F4-1 | 9.00 | 0 | 16.31 | 25.0 |
| F4-2 | 9.00 | 2.25 | 7.05 | 20.0 |
| F6-1 | 13.50 | 0 | 9.70 | 20.0 |
| F6-2 | 13.50 | 2.25 | 6.79 | 20.0 |
| F8-1 | 18.00 | 0 | 7.45 | 18.0 |
| F8-2 | 18.00 | 4.50 | 5.68 | 18.0 |
| S2-1 | 4.50 | 0 | 28.39 | 37.0 |
| S2-2 | 4.50 | 2.25 | no data | no data |
| S4-1 | 9.00 | 0 | 24.40 | 25.0 |
| S4-2 | 9.00 | 2.25 | 24.59 | 25.0 |
| S8-1 | 18.00 | 0 | 7.80 | 14.0 |
| S8-2 | 18.00 | 2.25 | 5.57 | 16.0 |

TABLE 6. TEST 5 RESULTS

Charge Weight = 8.0 lbs  Canopy Weight = 46.5 lbs

Canopy Size = 12" x 10' 1/2" x 0.105"

| Gage No. | Range R (ft) | Elevation h (ft) | Peak Side-on Overpressure (psi) | Total impulse (psi-msec) |
|---|---|---|---|---|
| F1-1 | 2.25 | 0 | 19.74 | 30.0 |
| F1-2 | 2.25 | 2.25 | 20.91 | 25.0 |
| F2-1 | 4.50 | 0 | 22.26 | 31.0 |
| F2-2 | 4.50 | 2.25 | 11.94 | 24.0 |
| F3-1 | 6.75 | 0 | 17.32 | 29.0 |
| F3-2 | 6.75 | 2.25 | 9.71 | 29.0 |
| F4-1 | 9.00 | 0 | 13.94 | 21.0 |
| F4-2 | 9.00 | 2.25 | 5.45 | 14.0 |
| F6-1 | 13.50 | 0 | 9.33 | 17.0 |
| F6-2 | 13.50 | 2.25 | 5.85 | 15.0 |
| F8-1 | 18.00 | 0 | 5.97 | 15.0 |
| F8-2 | 18.00 | 4.50 | 4.86 | 13.0 |
| S2-1 | 4.50 | 0 | 18.64 | 27.0 |
| S2-2 | 4.50 | 2.25 | 19.45 | 25.0 |
| S4-1 | 9.00 | 0 | 18.79 | 18.0 |
| S4-2 | 9.00 | 2.25 | 27.41 | 21.0 |
| S8-1 | 18.00 | 0 | 6.92 | 10.0 |
| S8-2 | 18.00 | 2.25 | 3.90 | 10.0 |

TABLE 7. TEST 6 RESULTS

Charge Weight = 8.0 lbs  Canopy Weight = 79.5 lbs

Canopy Size = 12" x 10' 3/4" x 0.189"

| Gage No. | Range R (ft) | Elevation h (ft) | Peak Side-on Overpressure (psi) | Total impulse (psi-msec) |
|---|---|---|---|---|
| F1-1 | 2.25 | 0 | 13.78 | 16.0 |
| F1-2 | 2.25 | 2.25 | 18.17 | 21.0 |
| F2-1 | 4.50 | 0 | 15.45 | 34.0 |
| F2-2 | 4.50 | 2.25 | 8.02 | 26.0 |
| F3-1 | 6.75 | 0 | 15.67 | 32.0 |
| F3-2 | 6.75 | 2.25 | 10.57 | 29.0 |
| F4-1 | 9.00 | 0 | 14.10 | 22.0 |
| F4-2 | 9.00 | 2.25 | 7.12 | 15.0 |
| F6-1 | 13.50 | 0 | 8.41 | 17.0 |
| F6-2 | 13.50 | 2.25 | 5.91 | 16.0 |
| F8-1 | 18.00 | 0 | 6.52 | 15.0 |
| F8-2 | 18.00 | 4.50 | 6.75 | 15.0 |
| S2-1 | 4.50 | 0 | 15.96 | 29.0 |
| S2-2 | 4.50 | 2.25 | 17.93 | 27.0 |
| S4-1 | 9.00 | 0 | 16.30 | 18.0 |
| S4-2 | 9.00 | 2.25 | 23.94 | 22.0 |
| S8-1 | 18.00 | 0 | 6.56 | 11.0 |
| S8-2 | 18.00 | 2.25 | 3.90 | 11.0 |

TABLE 8. TEST 7 RESULTS

Charge Weight = 8.0 lbs  Canopy Weight = 119.0 lbs

Canopy Size = 18" x 10' 3/4" x 0.189"

| Gage No. | Range R (ft) | Elevation h (ft) | Peak Side-on Overpressure (psi) | Total Impulse (psi-msec) |
|---|---|---|---|---|
| F1-1 | 2.25 | 0 | 12.93 | 26.0 |
| F1-2 | 2.25 | 2.25 | 12.61 | 25.0 |
| F2-1 | 4.50 | 0 | 10.60 | 27.0 |
| F2-2 | 4.50 | 2.25 | 6.98 | 23.0 |
| F3-1 | 6.75 | 0 | 9.64 | 26.0 |
| F3-2 | 6.75 | 2.25 | 8.13 | 25.0 |
| F4-1 | 9.00 | 0 | 8.38 | 19.0 |
| F4-2 | 9.00 | 2.25 | 5.13 | 13.0 |
| F6-1 | 13.50 | 0 | 7.57 | 15.0 |
| F6-2 | 13.50 | 2.25 | 4.88 | 14.0 |
| F8-1 | 18.00 | 0 | 7.56 | 13.0 |
| F8-2 | 18.00 | 4.50 | 5.07 | 13.0 |
| S2-1 | 4.50 | 0 | 13.99 | 25.0 |
| S2-2 | 4.50 | 2.25 | 10.80 | 24.0 |
| S4-1 | 9.00 | 0 | 13.23 | 15.0 |
| S4-2 | 9.00 | 2.25 | 16.18 | 18.0 |
| S8-1 | 18.00 | 0 | 5.62 | 10.0 |
| S8-2 | 18.00 | 2.25 | 3.86 | 10.0 |

TABLE 9. TEST 8

Charge Weight = 15.0 lbs

No Canopy

| Gage No. | Range R (ft) | Elevation h (ft) | Peak Side-on Overpressure (psi) | Total Impulse (psi-msec) |
|---|---|---|---|---|
| F1-1 | 2.25 | 0 | 39.34 | 35.0 |
| F1-2 | 2.25 | 2.25 | no data | no data |
| F2-1 | 4.50 | 0 | 39.30 | 33.0 |
| F2-2 | 4.50 | 2.25 | 20.94 | 50.0 |
| F3-1 | 6.75 | 0 | 31.11 | 29.0 |
| F3-2 | 6.75 | 2.25 | no data | no data |
| F4-1 | 9.00 | 0 | 23.08 | 30.0 |
| F4-2 | 9.00 | 2.25 | 8.38 | 27.0 |
| F6-1 | 13.50 | 0 | 14.20 | 25.0 |
| F6-2 | 13.50 | 2.25 | 7.80 | 23.0 |
| F8-1 | 18.00 | 0 | 9.14 | 22.0 |
| F8-2 | 18.00 | 4.50 | 6.00 | 21.0 |
| S2-1 | 4.50 | 0 | 41.65 | 39.0 |
| S2-2 | 4.50 | 2.25 | no data | no data |
| S4-1 | 9.00 | 0 | 31.16 | 32.0 |
| S4-2 | 9.00 | 2.25 | 36.33 | 37.0 |
| S8-1 | 18.00 | 0 | 11.45 | 19.0 |
| S8-2 | 18.00 | 2.25 | 7.41 | 17.0 |

TABLE 10. TEST 9 RESULTS

Charge Weight = 15.0 lbs  Canopy Weight = 45.5 lbs

Canopy Size = 12" x 10' 1/4" x 0.105"

| Gage No. | Range R (ft) | Elevation h (ft) | Peak Side-on Overpressure (psi) | Total impulse (psi-msec) |
|---|---|---|---|---|
| F1-1 | 2.25 | 0 | 33.14 | 32.0 |
| F1-2 | 2.25 | 2.25 | 37.15 | 75.0 |
| F2-1 | 4.50 | 0 | 26.48 | 18.0 |
| F2-2 | 4.50 | 2.25 | 47.63 | 88.0 |
| F3-1 | 6.75 | 0 | 23.76 | 18.0 |
| F3-2 | 6.75 | 2.25 | no data | no data |
| F4-1 | 9.00 | 0 | 13.16 | 25.0 |
| F4-2 | 9.00 | 2.25 | 4.91 | 19.0 |
| F6-1 | 13.50 | 0 | 7.53 | 21.0 |
| F6-2 | 13.50 | 2.25 | 5.16 | 20.0 |
| F8-1 | 18.00 | 0 | 5.89 | 21.0 |
| F8-2 | 18.00 | 4.50 | 4.87 | 19.0 |
| S2-1 | 4.50 | 0 | 36.50 | 36.0 |
| S2-2 | 4.50 | 2.25 | 53.30 | 80.0 |
| S4-1 | 9.00 | 0 | 26.18 | 24.0 |
| S4-2 | 9.00 | 2.25 | 32.07 | 28.0 |
| S8-1 | 18.00 | 0 | 11.63 | 16.0 |
| S8-2 | 18.00 | 2.25 | 6.23 | 14.0 |

TABLE 11. TEST 10

Charge Weight = 15.0 lbs  Canopy Weight = 79.5 lbs

Canopy Size = 12" x 10' 3/4" x 0.189"

| Gage No. | Range R (ft) | Elevation h (ft) | Peak Side-on Overpressure (psi) | Total impulse (psi-msec) |
|---|---|---|---|---|
| F1-1 | 2.25 | 0 | 13.71 | 27.0 |
| F1-2 | 2.25 | 2.25 | 27.74 | 31.0 |
| F2-1 | 4.50 | 0 | 24.67 | 40.0 |
| F2-2 | 4.50 | 2.25 | 38.14 | 52.0 |
| F3-1 | 6.75 | 0 | 22.44 | 38.0 |
| F3-2 | 6.75 | 2.25 | no data | no data |
| F4-1 | 9.00 | 0 | 11.95 | 26.0 |
| F4-2 | 9.00 | 2.25 | 5.21 | 19.0 |
| F6-1 | 13.50 | 0 | 8.05 | 23.0 |
| F6-2 | 13.50 | 2.25 | 5.36 | 21.0 |
| F8-1 | 18.00 | 0 | 8.00 | 22.0 |
| F8-2 | 18.00 | 4.50 | 6.86 | 19.0 |
| S2-1 | 4.50 | 0 | 35 52 | 37.0 |
| S2-2 | 4.50 | 2.25 | 36.93 | 29.0 |
| S4-1 | 9.00 | 0 | 22.26 | 23.0 |
| S4-2 | 9.00 | 2.25 | 34.21 | 31.0 |
| S8-1 | 18.00 | 0 | 11.06 | 16.0 |
| S8-2 | 18.00 | 2.25 | 6.26 | 15.0 |

TABLE 12. CALCULATED SURFACE PRESSURE (NO WALL) FROM P-397

W = 1.13 lb $H/W^{1/3}$ = 2.16

| R (ft) | B (psi) | i (psi-msec) | Z ($ft/lb^{1/3}$) |
|---|---|---|---|
| 3.71 | 33.3 | 22 | 3.56 |
| 5.96 | 30.1 | 13 | 5.72 |
| 8.21 | 15.1 | 10 | 7.88 |
| 10.46 | 9.3 | 8 | 10.04 |
| 14.96 | 5.0 | 6 | 14.36 |
| 19.46 | 3.3 | 4 | 18.68 |

W = 9.03 lb $H/W^{1/3}$ = 1.08

| R (ft) | B (psi) | i (psi-msec) | Z ($ft/lb^{1/3}$) |
|---|---|---|---|
| 3.71 | 388.2 | 42 | 1.78 |
| 5.96 | 149.0 | 53 | 2.86 |
| 8.21 | 77.0 | 39 | 3.94 |
| 10.46 | 41.5 | 30 | 5.02 |
| 14.96 | 18.2 | 22 | 7.18 |
| 19.46 | 10.7 | 17 | 9.34 |

W = 16.94 lb $H/W^{1/3}$ = 0.88

| R (ft) | B (psi) | i (psi-msec) | Z ($ft/lb^{1/3}$) |
|---|---|---|---|
| 3.71 | 562.0 | 46 | 1.44 |
| 5.96 | 231.0 | 60 | 2.32 |
| 8.21 | 119.0 | 61 | 3.19 |
| 10.46 | 71.5 | 46 | 4.07 |
| 14.96 | 28.8 | 32 | 5.82 |
| 19.46 | 16.4 | 26 | 7.57 |

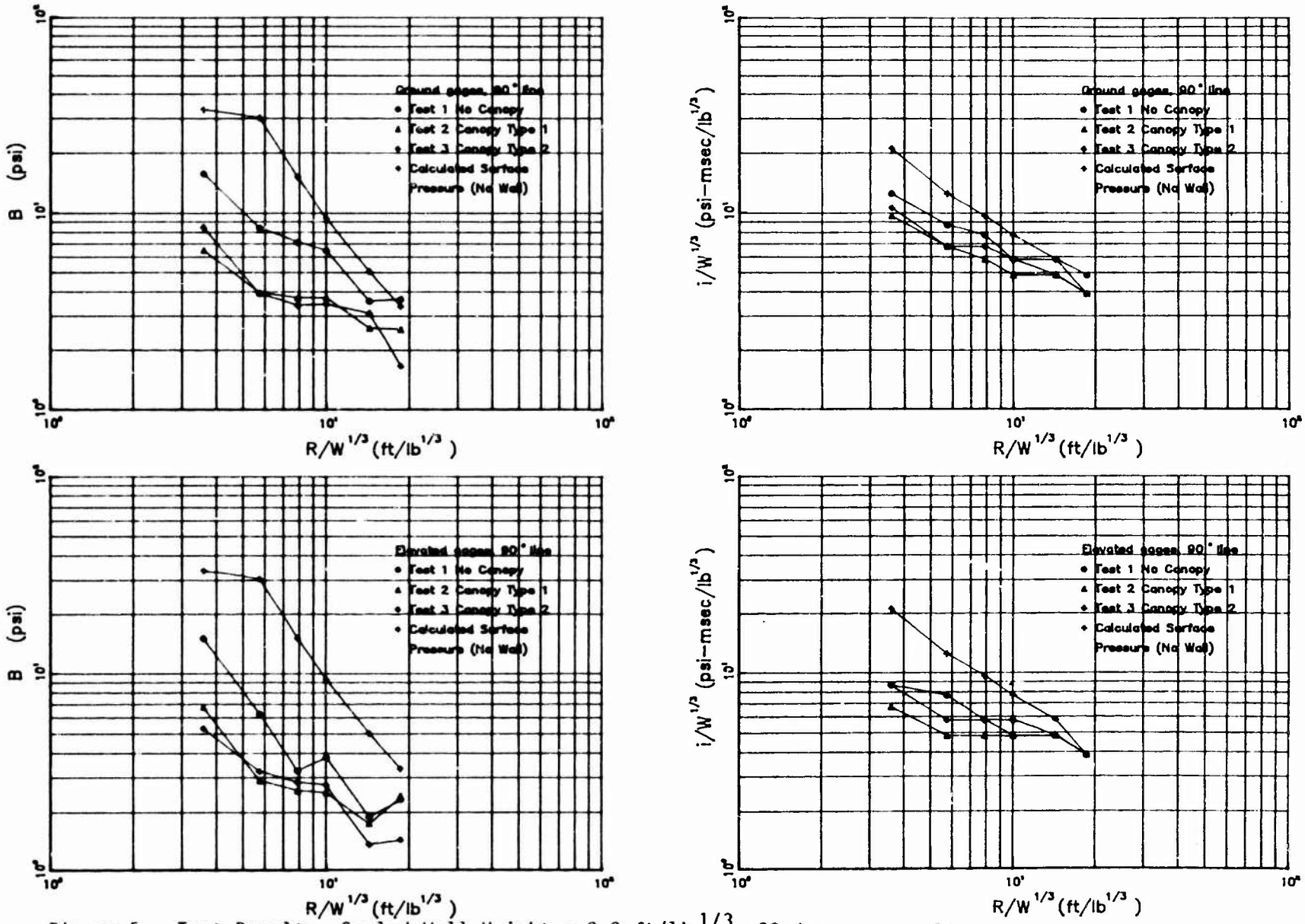



Figure 5. Test Results, Scaled Wall Height = 2.2 ft/lb $^{1/3}$, 90 degree gage line.

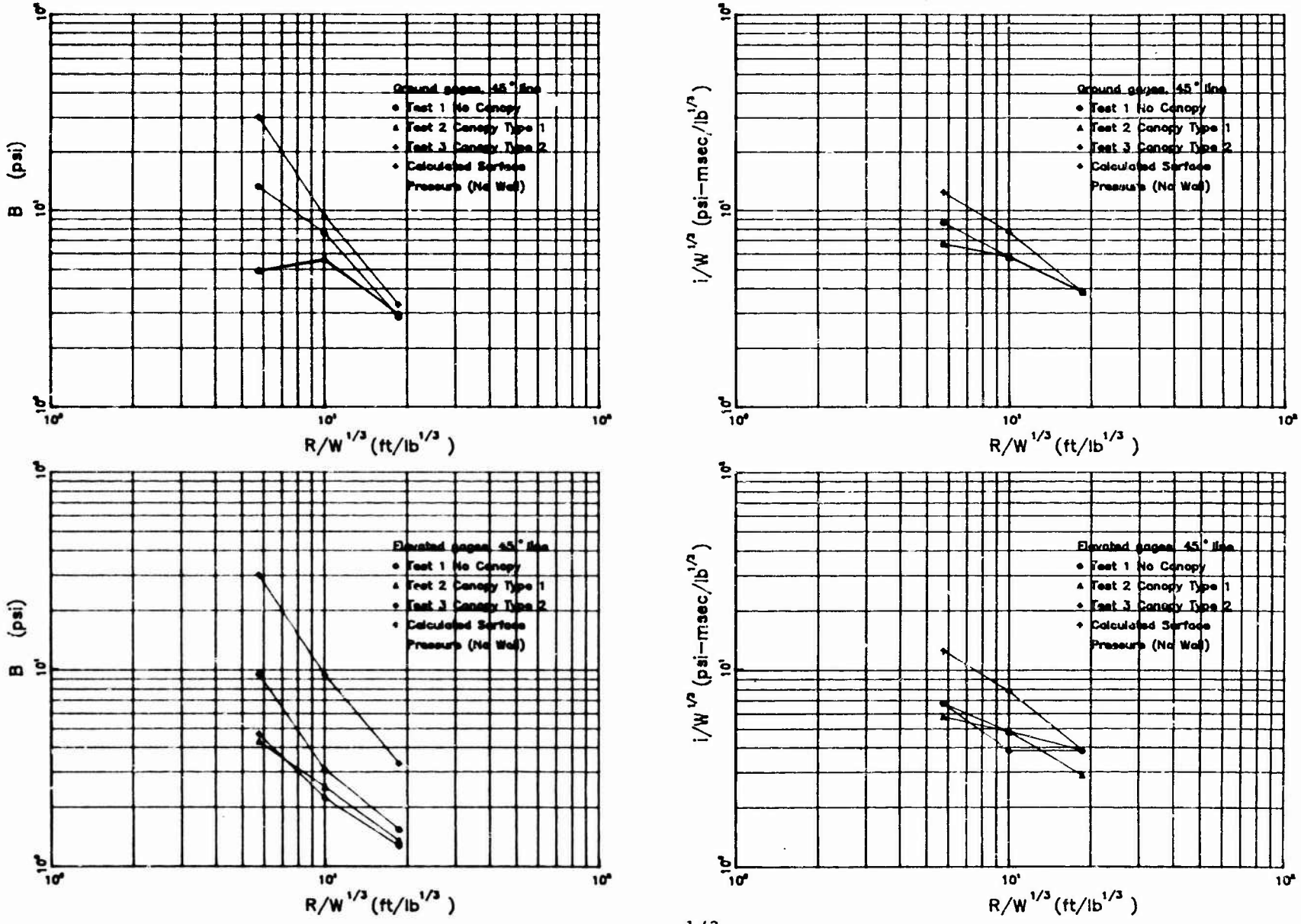



Figure 6. Test Results, Scaled Wall Height = 2.2 ft/lb$^{1/3}$, 45 degree gage line.

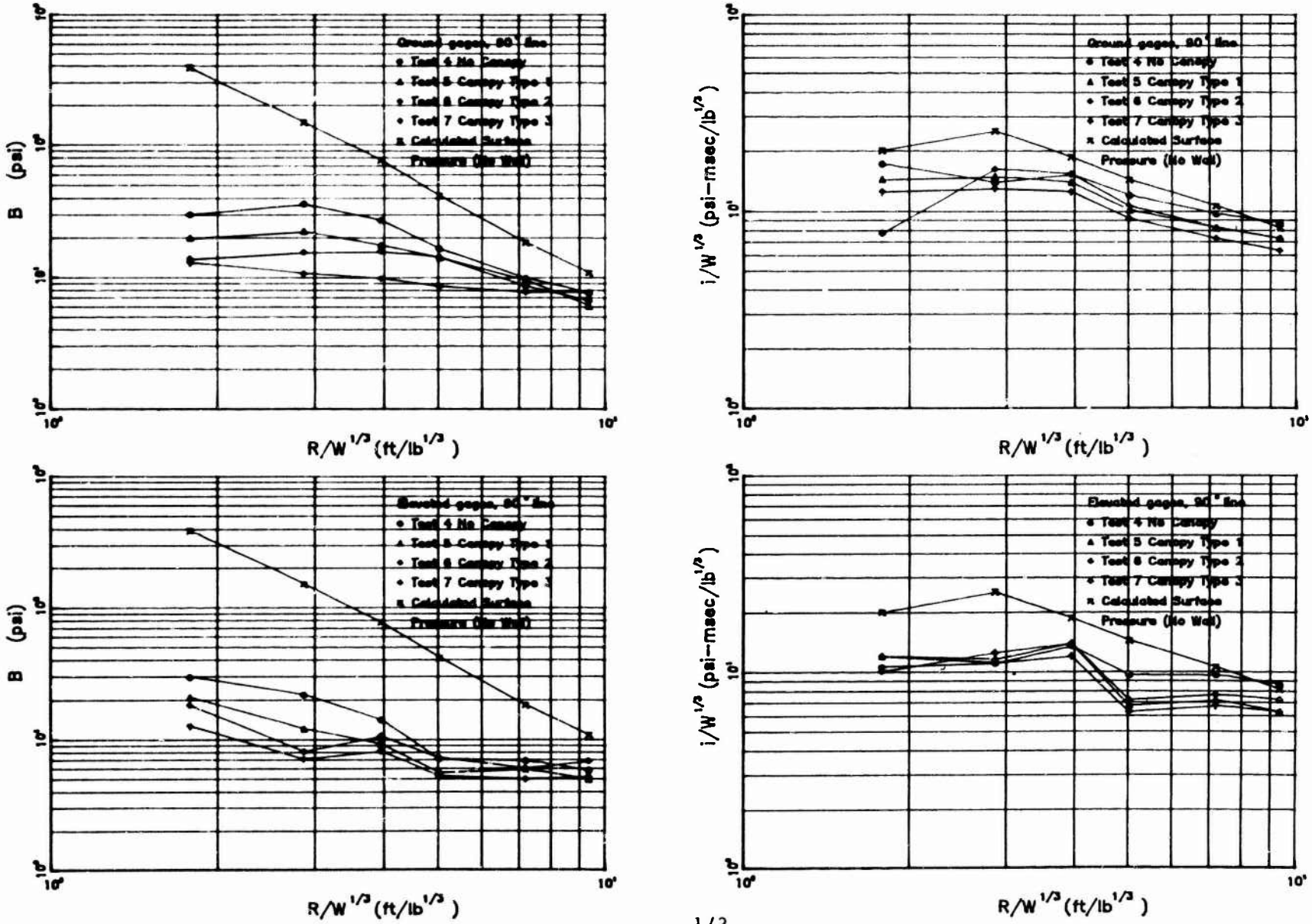



Figure 7. Test Results, Scaled Wall Height = 1.1 ft/lb$^{1/3}$, 90 degree gage line.

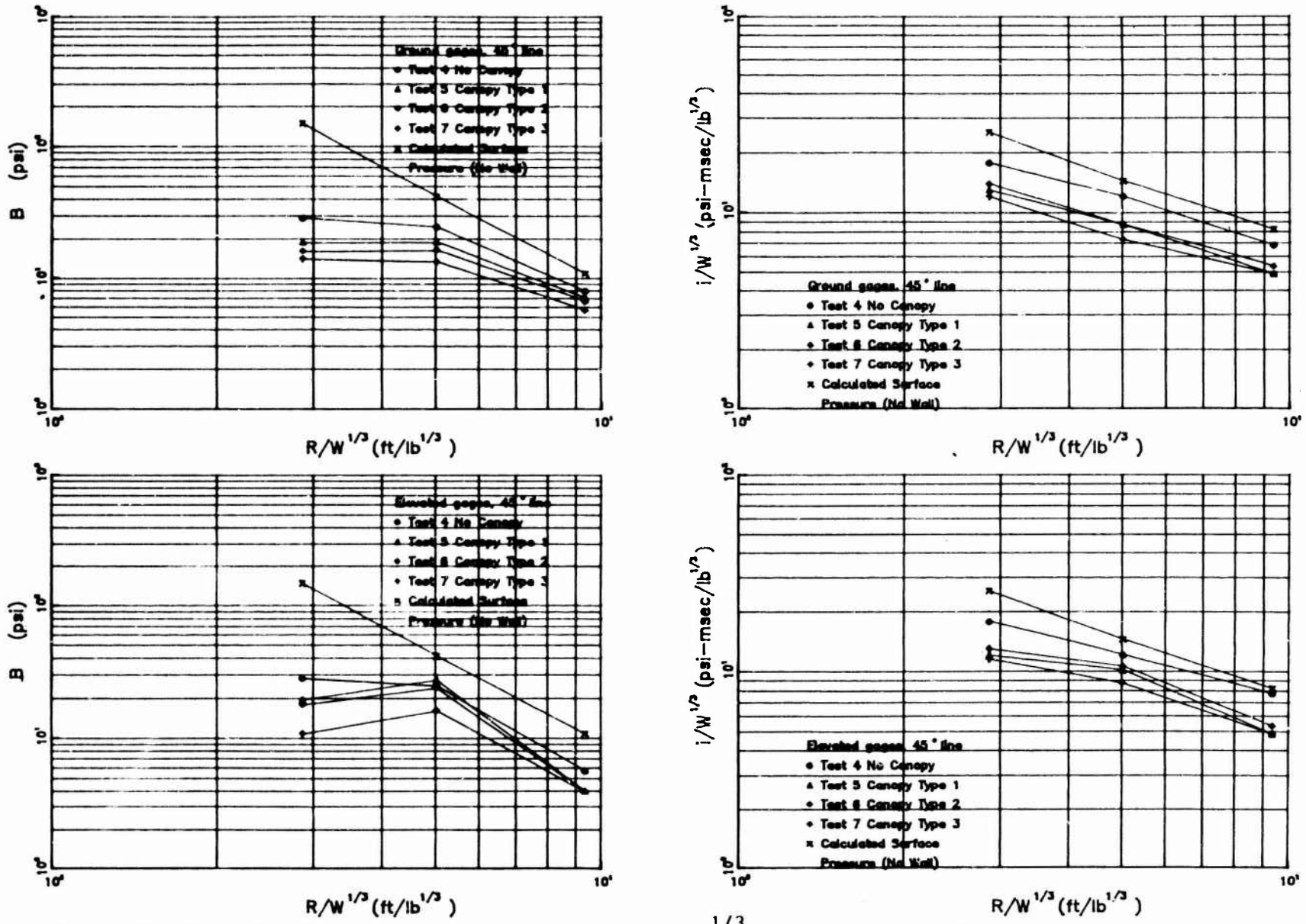



Figure 8. Tests Results, Scaled Wall Height = 1.1 ft/lb$^{1/3}$, 45 degree gage line.

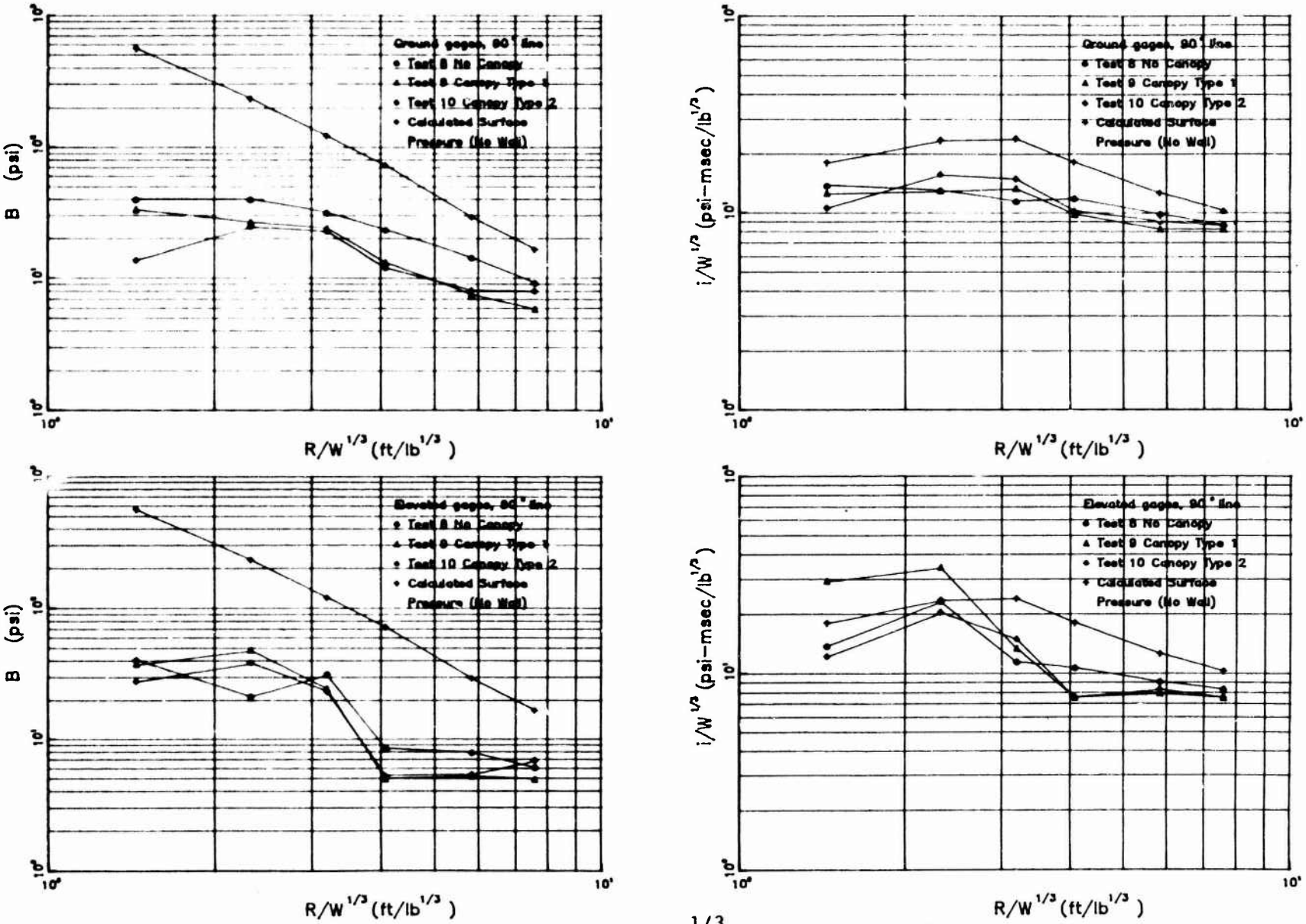



Figure 9. Test Results, Scaled Wall Height = 0.9 ft/lb$^{1/3}$, 90 degree gage line.

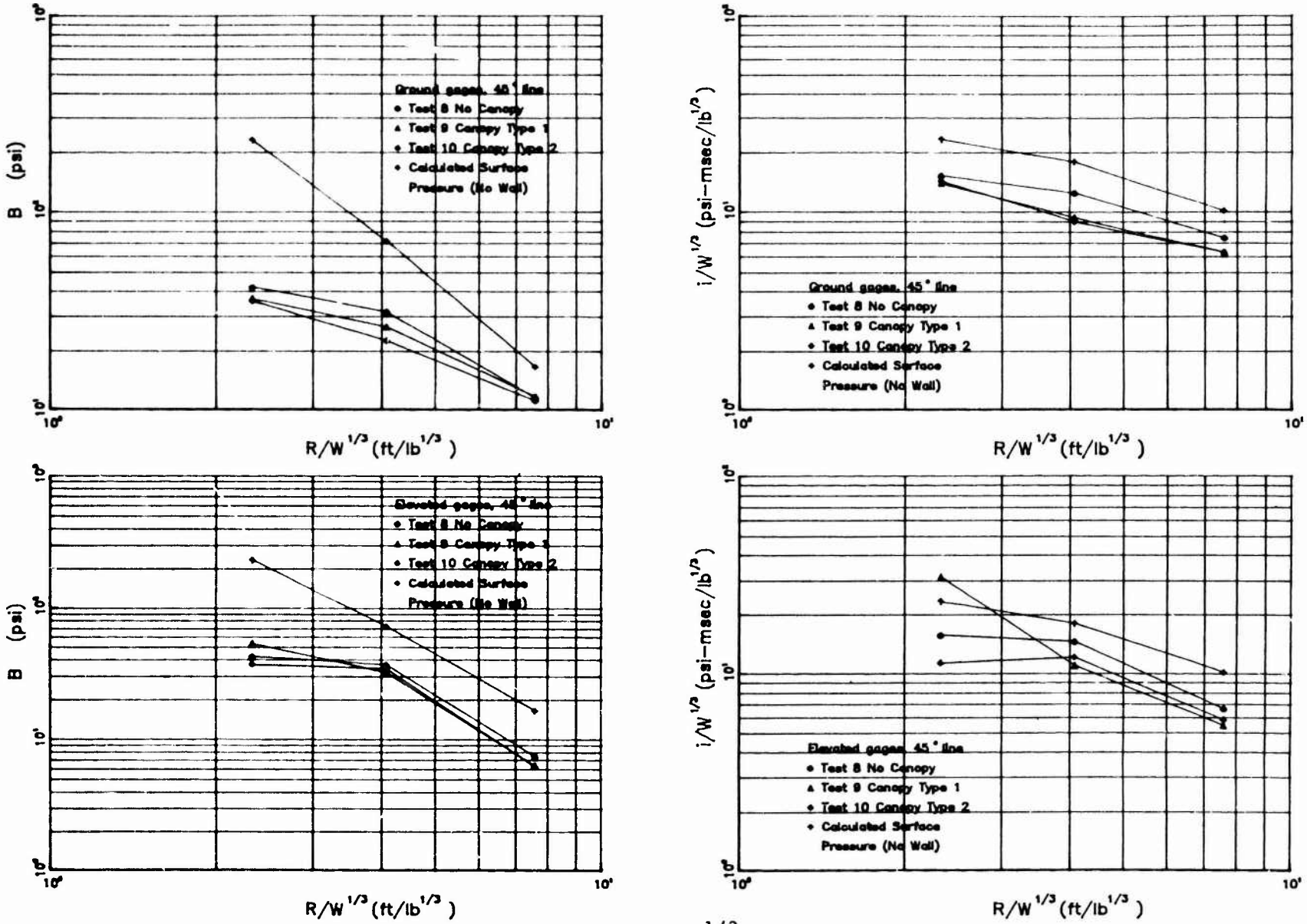



Figure 10. Test Results, Scaled Wall Height = 0.9 ft/lb$^{1/3}$, 45 degree gage line.

TABLE 13. TEST SCHEDULE (SEPTEMBER 1986 PLANNED COMPLETION DATE)

| TEST # | $W_{C4}$ (lbs) | Scaled Wall Heigl (ft) | r (ft) | z (ft) |
|---|---|---|---|---|
| 1 | 1.0 | 2.16 | 1.0 | 1.0 |
| 2 | 1.0 | 2.16 | 2.0 | 1.0 |
| 3 | 8.0 | 1.08 | 1.0 | 1.0 |
| 4 | 8.0 | 1.08 | 2.0 | 1.0 |
| 5 | 15.0 | 0.88 | 1.0 | 1.0 |
| 6 | 15.0 | 0.88 | 2.0 | 1.0 |
| 7 | 45.6 | 0.63 | 2.5 | 1.23 |
| 8 | 45.6 | 0.63 | 2.5 | 1.23 |
| 9 | 1.0 | 0.0 | * | 1.0 |
| 10 | 1.0 | 0.0 | * | 1.0 |
| 11 | 8.0 | 0.0 | * | 1.0 |
| 12 | 8.0 | 0.0 | * | 1.0 |
| 13 | 15.0 | 0.0 | * | 1.0 |
| 14 | 15.0 | 0.0 | * | 1.0 |

* For the tests with no wall, the charge will be positioned relative to the pressure transducers.

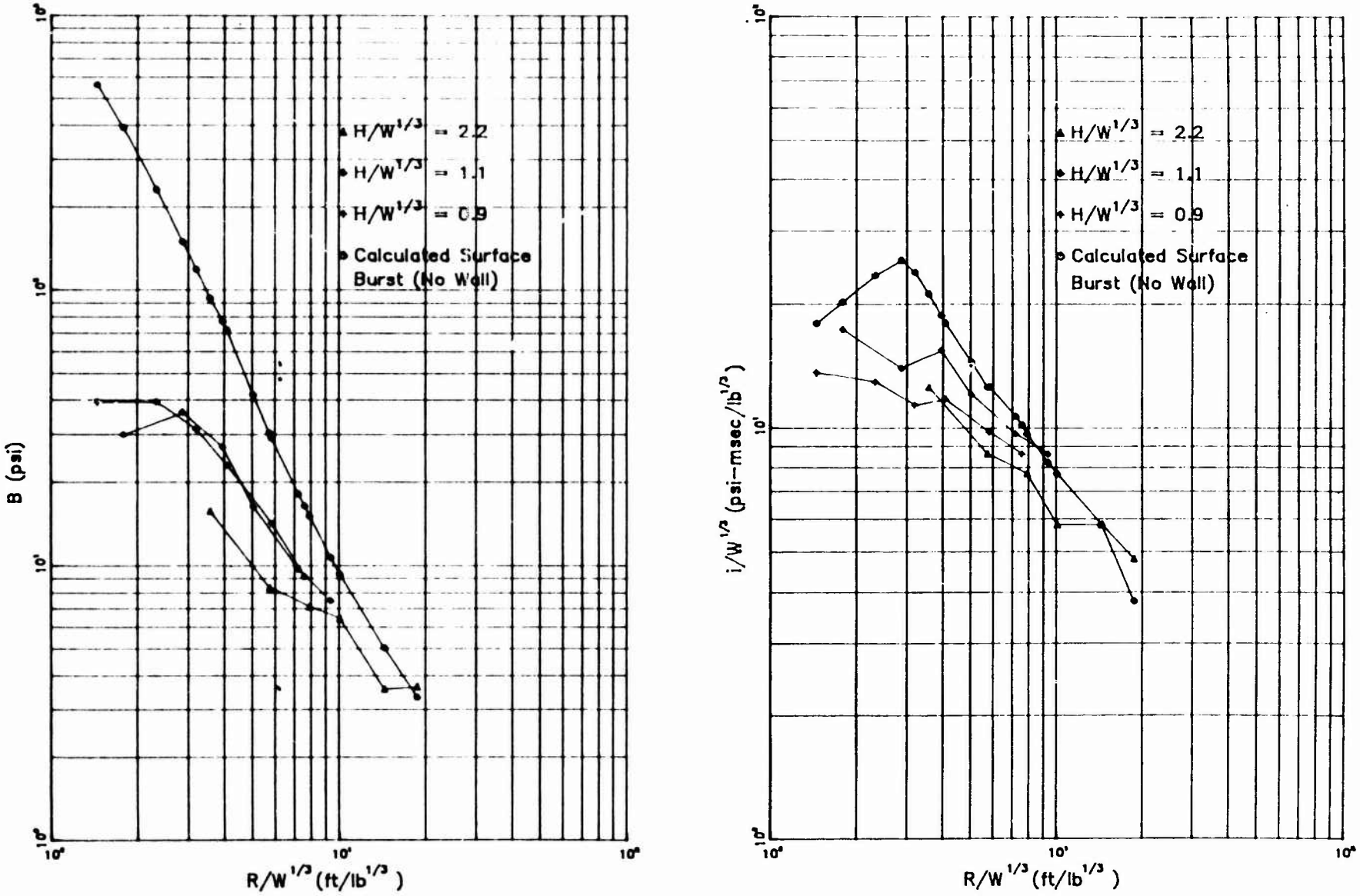



Figure 11. Preliminary design curves. Surface gages, no canopy.

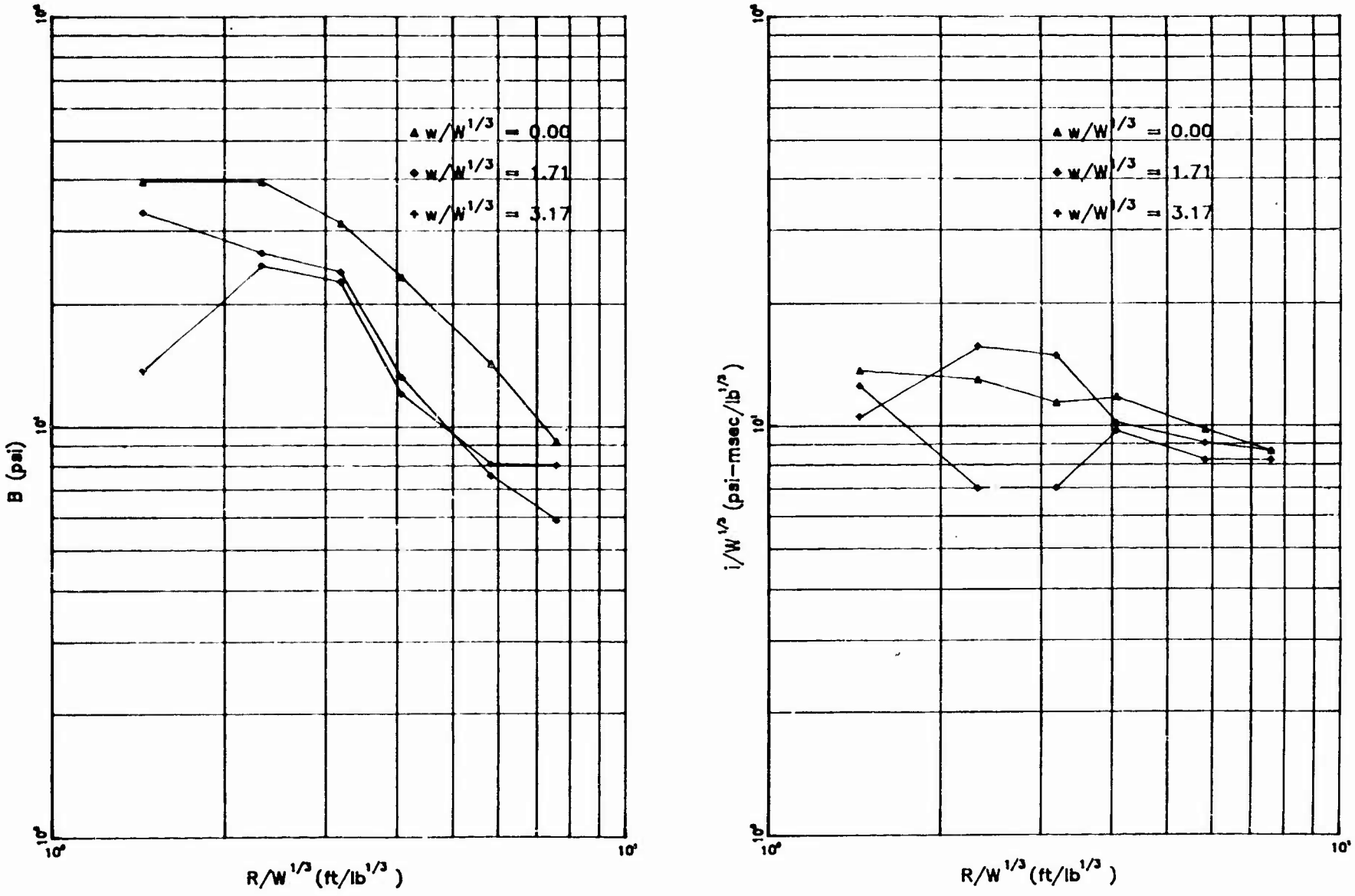



Figure 12. Preliminary design curves. Surface gages, wall with canopies, $W_{C4}$ = 15 lbs.

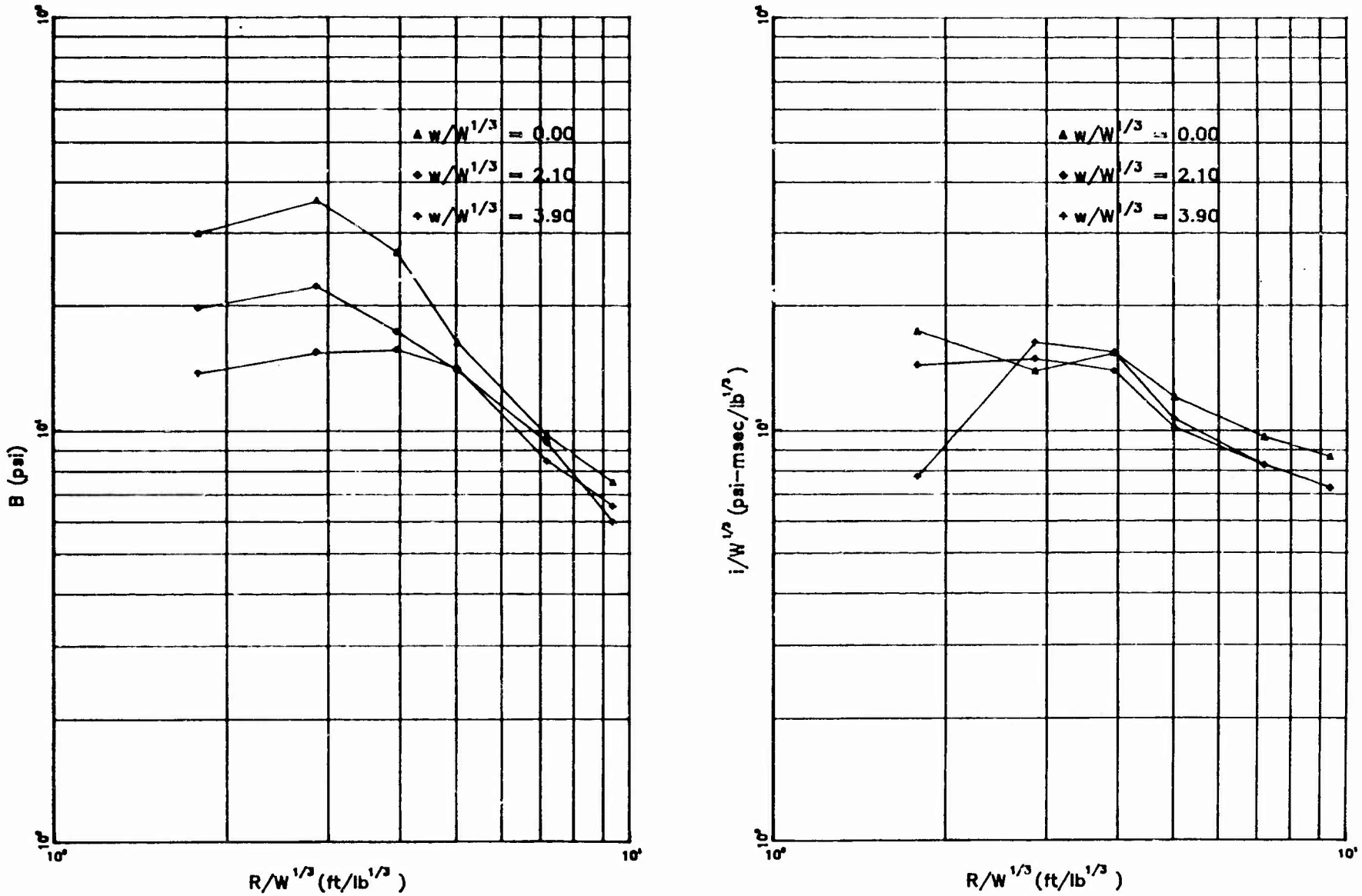



Figure 13. Preliminary design curves. Surface gages, wall with canopies, $W_{C4}$ = 8 lbs.

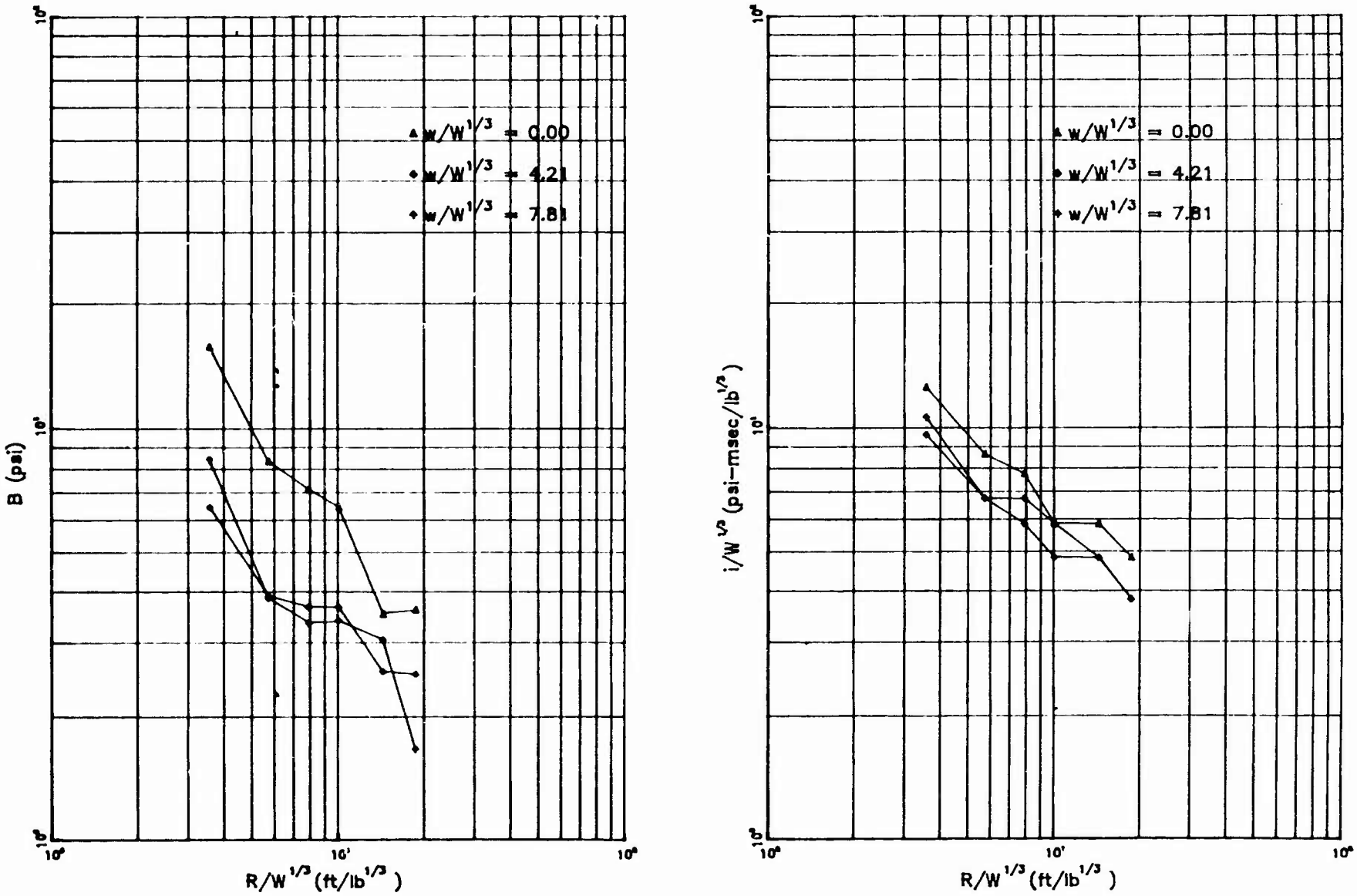



Figure 14. Preliminary design curves. Surface gages, wall with canopies, $W_{C4}$ = 1 lb.

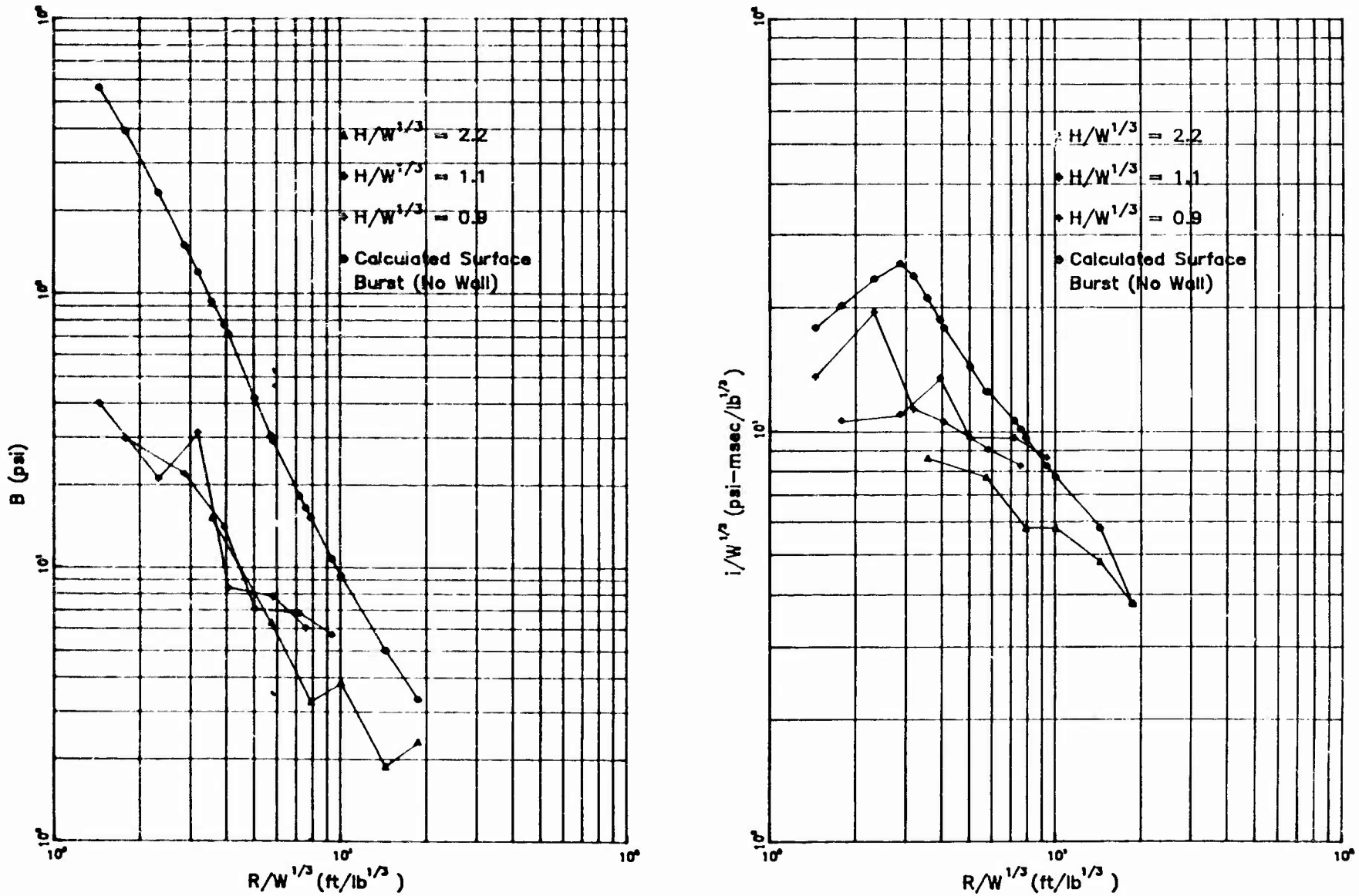



Figure 15. Preliminary design curves. Elevated gages, no canopy.